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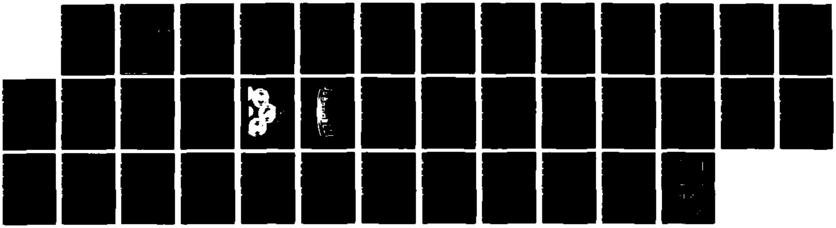

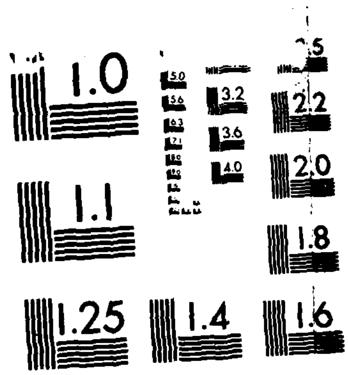
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EVALUATION OF ARMY ENGINE OILS IN HYDRAULIC/POWER TRANSMISSION SYSTEM COMPONENTS

FINAL REPORT
BFLRF No. 203

By

H.W. Marbach, Jr.
S.J. Lestz
Belvoir Fuels and Lubricants Research Facility (SwRI)
Southwest Research Institute
San Antonio, Texas

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The objective of the MACI Hydraulic System and Components Program is to perform technical evaluation and assessment of commercially available qualified and fielded Army engine oils and to determine if such oils can be used as hydraulic fluids in Army commercial construction equipment and material handling equipment.

Five Army specification engine lubricants--four MIL-L-2104D (one grade 10W, one grade 30, two grade 15W-40) and one MIL-L-46167, grade 0W-20--were evaluated using four critical component performance tests used by manufacturers.

Data compiled from this and previous work have shown that the limiting factors of the Army engine oils used as hydraulic and multipurpose power transmission fluids appear to be (1) wet-brake chatter

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noise, (2) hydraulic pump wear problems with some piston pumps using MIL-L-46167 Arctic engine oils at temperatures hotter than expected Arctic conditions, and possibly (3) copper corrosion. The prime area of concern is the wet-brake chatter noise.

FOREWORD

The work reported herein was conducted at the Belvoir Fuels and Lubricants Research Facility (SwRI), Southwest Research Institute, San Antonio, TX, under Contract No. DAAK70-84-C-0071 and covers the period August 1984 - November 1985. The work was funded by Belvoir Research and Development Center, Ft. Belvoir, VA. Contracting officer's representative was Dr. H. Spitzer, Fuels and Lubricants Division/STRBE-VF, and the technical monitor was Mr. M.E. LePera, Chief, Fuels and Lubricants Division (STRBE-VF), Belvoir Research and Development Center.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

I. INTRODUCTION

The Army's military construction mission in many ways resembles the tasks of civilian construction enterprises. These enterprises purchase their equipment from manufacturers who must compete for that business by producing efficient modern equipment by continuous improvements through research and development. Recognizing the same need for constant modernization as well as being confronted with decreasing R&D budgets, the Army adopted a policy of procuring construction type (CCE) and material handling equipment (MHE) from commercial sources.(1)* Today the majority of CCE and MHE utilized by the Army is of the commercial or modified commercial type. Obvious advantages exist for this policy, but certain problems required resolution to make the CCE and MHE program successful. The fluids used in the various multipurpose hydraulic systems are considered as components of the total system and are usually provided under commercial proprietary fluid specifications. Using these various manufacturers' fluid specifications over a period of time would obviously lead to a proliferation of proprietary hydraulic fluids creating a logistic burden to the supply system. However, using the fluids that are not authorized by the equipment manufacturers could lead to the loss of the equipment warranty. Also, many of the manufacturers are reluctant to permit the use of other than specified fluids in their equipment.

For military CCE and MHE equipment, automotive engine oils meeting MIL-L-2104, Lubricating Oil, Internal Combustion Engine, Tactical Service (2), MIL-L-46167, Lubricating Oil, Internal Combustion Engine, Arctic (3) and MIL-L-21260, Lubricating Oil, Internal Combustive Engine, Preservative and Break-In (4) have and are being used for practically all Army hydraulic and power transmission fluid applications.

With the introduction of the CCE and MHE program, John Deere and Company was awarded a contract to furnish a CCE item (front loader/backhoe tractor) which introduced the first wet-brake equipped vehicle into the Army inventory in 1975. Since subsequent contract procurements could be awarded to other companies, there was great concern within the Army as to potential supply problems since

* Underscored numbers in parentheses refer to the list of references at the end of this report.

each of these companies requires that its own proprietary fluid be used. The companies using wet-brake equipment indicated that MIL-L-2104C combat/tactical engine oils would not perform satisfactorily in their equipment systems. For this purpose, Belvoir R&D Center initiated a test program in 1975 to establish the performance level of a number of existing military specification lubricants along with several commercial and Government stocked hydraulic and power transmission fluids in relation to the John Deere JDM-J20A factory and service fill specification.(5) Only one of the lubricants, a MIL-L-2104C, Grade 10W passed the JDM-J20A specification and was put on a field test. In the past, the only way to differentiate between acceptable and unacceptable components has been extensive (expensive) end-item testing. This problem existed because no standardized requirements and test methods have been available to component manufacturers or users. Therefore, this project was initiated in April 1980 as an important element in Belvoir R&D Center overall Military Adaptation of Commercial Item (MACI) Hydraulic System and Component Program.

II. OBJECTIVE

The MACI program is to provide a process in which the government may coordinate its effort with industrial users and hydraulic/power transmissions component manufacturers to achieve the acceptance of standardization requirements and tests to evaluate systems and components. Once adopted, test data generated by commercial laboratories can be used by the Army to verify the acceptability of hydraulic components and systems.

The specific objective of the MACI program is to perform technical evaluation and assessment of commercially available qualified and fielded Army engine oils and to determine if such oils can be used as hydraulic fluids in Army commercial construction equipment and material handling equipment.

III. PREVIOUS WORK SUMMARY

Nineteen military specification lubricants--eight oils qualified under MIL-L-2104C, grade 10W and grade 30; one multiviscosity MIL-L-46152 (6), grade 10W-30; five

MIL-L-46152B (6), grade 15W-40; two MIL-L-46167, grade 0W-20; one MIL-H-46001C (7), grade 10; one MIL-L-21260C, grade 10W; and one multiviscosity oil satisfying MIL-L-2104C engine lubricant requirements--were extensively evaluated using twelve selected tests required by manufacturers and one test developed by Belvoir Fuels and Lubricants Research Facility (BFLRF) at SwRI in conjunction with John Deere personnel.(8-10) These tests are:

(a) Wet-Brake Friction (Caterpillar, TO-2)
(b) Wet-Brake Friction (Detroit Diesel Allison, C-3)
(c) Pump Anti-Wear (Detroit Diesel Allison, C-3)
(d) THM Transmission Oil Oxidation Stability (Detroit Diesel Allison, C-3)
(e) Seal Compatibility (Detroit Diesel Allison, C-3)
(f) Vickers Vane Pump Wear (ASTM, D 2882)
(g) Dynamic Corrosion (Sundstrand Axial Piston Pump Wear Contamination)
(h) Wet-Brake Noise (Massey-Ferguson In-Vehicle Test)
(i) Water Tolerance (John Deere JDM-J20A)
(j) Copper Corrosion (Mod. ASTM D 130)
(k) Sonic Shear Stability Viscosity (ASTM D 2603 Mod.)
(l) Fluoroelastomer Material Compatibility (Caterpillar, TO-3) and
(m) Wet-Brake Chatter and Hydraulic Performance (BFLRF and John Deere).

From the data developed, the Army engine lubricants passed approximately 90 percent of all the tests. All the military test lubricants were considered to be borderline to excellent.

The only exceptions were one MIL-L-46167, grade 0W-20 and one MIL-L-21260C, grade 10W. The MIL-L-46167 was considered a failure in the pump wear and frictional characteristics and the MIL-L-21260C failed the TO-2 friction retention test. The borderline areas appeared in wet-clutch frictional characteristics, slower hydraulic system response times, more wet-brake chatter noise, and copper corrosion tests. None of these areas were considered excessive to the point of substantially hindering operations (primarily annoying to the operator), but they could cause some long-term wear and stress problems. The grade 10W, MIL-L-2104C that passed the John Deere JDM-J20A specification in an earlier program and underwent field evaluations for 4.5 years performed as well as the JDM-J20A

fluid-filled tractors in all the hydraulic and power transmission areas.(9) Listings were also compiled showing all the present/proposed items, components and systems, and their lubricant requirements.(8) Also, 24 manufacturers of hydraulic and power transmission systems and components were surveyed, in view of Belvoir F&L Research Facility test results, to identify the equipment which these manufacturers claimed could not operate properly with these military engine oils. The majority of the component manufacturers believed that single-grade lubricants would operate satisfactorily in their components when used in the proper viscosity range. But some (especially Denison and Vickers) expressed concern with the use of multiviscosity lubricants because of the shear involved with hydraulic systems. Also, some suppliers were concerned that some military engine oil specifications did not have any pump wear tests and that some had no requirements for wet frictional characteristics. In addition, some equipment manufacturers expressed concern (especially John Deere and Ford) about potential wet-brake chatter noise. Personnel from Belvoir F&L Research Facility have met and worked with the ASTM Multipurpose Power Transmission Fluid Panel and their members. This panel is working to complete the adoption of the multipurpose power transmission fluid specification which will address some of these concerns.

IV. TEST DETAILS

A. Critical Component Test Selection

Results from the previous MACI programs and past 6.2 funded R&D efforts show that numerous tests are required if all potential CCE/SMHE components are to be addressed. The list of procured and proposed CCE/SHME shows a broad range of equipment representing many different suppliers. In addition, any lubricant selected for use in the CCE/SHME hydraulic and multipurpose power transmissions systems must also be acceptable for use in the Army tactical fleet engines. The military specification lubricants should have three major performance areas of concern: (1) engine protection; (2) gear/pump protection; and (3) wet-brake/clutch frictional retention. The engine protection is accomplished with the test requirements of MIL-L-2104C/D, MIL-L-46167A, and MIL-L-46152B specifications (see Table 1). The pump wear protection is provided for in only the MIL-L-46167/A but

TABLE 1. LUBRICANT MAJOR PERFORMANCE AREAS

	MIL-L-Specification				
Performance Tests	2104C	2104D	46152B	46167	46167A
Engine	Y*	Y	Y	Y	Y
Final Drive Gear	N**	N	N	N	N
Hydraulic Pump	N	N	N	Y	Y
Frictional					
Wet-Clutch	N	Y	N	N	Y
Wet-Brake	N	N	N	N	N

* Y = Yes
** N = No

not in either MIL-L-2104C/D or MIL-L-46152B. Also, no final drive gear wear test is included in MIL-L-2104C/D, MIL-L-46152B, and MIL-L-46167/A specifications. The wet-frictional protection is also not provided for in MIL-L-2104C, MIL-L-46152B, and MIL-L-46167. The MIL-L-2104D and the new revised MIL-L-46167A specifications oils must meet the Detroit Diesel Allison C-3 and Caterpillar TO-2 friction retention tests which should make those products acceptable for most hydraulic and power transmission applications. Finally, none of the military engine oils has any test requirements for wet-brake chatter noise and capacity. These wet-brake/wet-clutch systems use a wide variety of frictional materials such as graphitic, asbestos, bronze, and paper. Therefore, not all Army equipment using wet-brake systems would be expected to perform well using military engine oils. Some of the military lubricants failed the modified ASTM D 130 Copper Corrosion test, and it was deemed necessary to consider this as an area for concern. From the above discussions, it was considered important to establish the performance of selected military engine oils in the tests listed below:

(a) Denison HF-0 Piston and Vane Pump Test
(b) Transmission Final Drive Gear Wear Test JDM-J20A, Procedure 5.
(c) ASTM and CEC Sintered Bronze Wet-Brake Fluid Friction Test and
(d) Copper Corrosion ASTM D 130 Mod.

B. Test Lubricants

The test lubricants used for testing were selected because of their use in the Army system and extensive background test data. Five lubricants were selected: four MIL-L-2104D--one grade 10W, one grade 30, two grade 15W-40; and one MIL-L-46167, grade 0W-20. The MIL-L-2104D, grade 10W and 30 were also selected because both are used as Army reference lubricants for proving ground and equipment acceptance testing. The two MIL-L-2104D, grade 15W-40 lubricants were selected because they were also qualified under MIL-L-46152B and one failed the copper corrosion test. The 15W-40 lubricant would be expected to be used quite extensively. The MIL-L-46167 was also selected because of a history of borderline hydraulic pump performance in various pump tests.

Each of the test lubricants was assigned a numerical code for use in this program. Table 2 summarizes the assigned code designation along with specification and grade of each product. A summary of the results of the physical and chemical characteristics can also be seen in Table 3.

TABLE 2. TEST LUBRICANTS EVALUATED

Lube No.	Grade	Specification
1	10W	MIL-L-2104D Army Reference Oil
2	30	MIL-L-2104D Army Reference Oil
3	15W-40	MIL-L-2104D Qualified Product
4	15W-40	MIL-L-2104D Qualified Product
5	0W-20	MIL-L-46167 Qualified Product

V. DISCUSSION OF TEST RESULTS

A summary of the overall performance of the lubricants in these tests can be seen in Table 4. The data from these results are shown in subsequent tables in the appendix.

TABLE 3. TEST LUBRICANTS PHYSICAL AND CHEMICAL CHARACTERISTICS

MIL-Specification	2104D*	2104D*	46152B 2104D	46152B 2104D	46167
Lubricant No.	1	2	3	4	5
Qualified Product, Grade	10W	30	15W-40	15W-40	0W-20
Lube Characteristics					
Viscosity, cSt					
40°C	39.9	95.8	112.2	104.2	30.3
100°C	6.2	11.1	15.2	14.3	5.8
VI	103	101	141	140	138
Acid No. (TAN)	2.5	2.6	2.6	2.6	3.0
Base No. (TBN)	7.3	7.4	6.8	5.3	5.2
Sulfated Ash	0.90	0.84	0.80	1.01	1.00
Elements, %					
Ba	<0.01	<0.01	<0.01	<0.01	0.20
Ca	<0.01	<0.01	<0.01	0.16	<0.01
Mg	<0.02	<0.02	0.11	0.04	0.09
P	0.11	0.12	0.09	0.11	0.12
S	0.46	0.55	0.40	0.50	0.48
Zn	0.13	0.13	0.10	0.13	0.14
N	0.062	0.067	0.073	0.054	0.039
B, ppm	0.0004	0.0009	0.0035	0.0088	<0.0001

* Army reference lubricants for Proving Ground and equipment acceptance testing.

TABLE 4. SUMMARY OF TEST PERFORMANCE RESULTS

Specification MIL-L-	2104D				46167
Lube No.	1	2	3	4	5
Test	10W	30	15W-40	15W-40	0W-20
Denison HF-0 Pump					
Piston	P*	P	P	P	F**
Vane	P	P	P	P	P
Trans. Final Drive Gear Wear	P	P	P	P	P
ASTM & CEC Sintered Bronze Wet-Brake					
Chatter	F	F	F	F	F
Relative Capacity	P	P	F	P	P
Copper Corrosion at 150°C	F	F	P	F	P

* P = Pass
** F = Fail

A. Denison HF-0 Piston and Vane Pump Test

When the Army engine oils are used in hydraulic systems that use both piston and vane pumps, antiwear additives are critical. Compounds which provide good antiwear protection in one type of hydraulic pump can be detrimental to another. Therefore, the five Army engine oils were evaluated in the Denison HF-0 Piston and Vane Pump (see Tables A-1 through A-5 of the appendix). This test consists of operating two pumps continuously at speeds up to 2500 rpm with the vane pump outlet pressure at 2500 psi and piston pump outlet pressure at 5000 psi. The piston pump requires 350 hp input and the vane pump requires 136 hp input. The test is conducted for 100 hours. The fluid temperature is maintained at 160°F (71°C) for the first 60 hours and at 210°F (99°C) for the last 40 hours. Pump parts

inspections are made at 30, 60, and 100 hours, and all the pump parts must be as good as when tested with the reference oil.

All five lubricants passed the vane pump part of the tests, but only four passed the piston pump part. The MIL-L-46167, grade 0W-20 Arctic engine oil was a borderline fail. The 0W-20 lubricant passed the 30- and 60-hour parts inspection in the piston pump and completed the 100 hours of testing (Table A-5). The problem occurred when the temperature was increased from 160°F (71°C) to 210°F (99°C) for the last 40 hours. At the 210°F (99°C) control temperature, case temperatures of 255°F are attained. The piston pump had a high degree of piston shoe scoring deposit buildup and discoloration (Figure 1) with the barrel support bearing showing some pitting (Figure 2). The MIL-L-46167 Arctic engine lubricants have exhibited a weakness in pump antiwear, especially at the higher operating temperatures (temperatures higher than expected for Arctic operating conditions). This weakness is apparently due to marginal viscosity resulting in loss of hydrodynamic film lubrication. The piston shoe deposit buildup was analyzed with an electron scanning microscope, which interfaces with an XRF analyzer and was determined to be primarily sulfur and iron.

B. Transmission Final Drive Gear Wear Test

The purpose of this test is to evaluate the antiwear and antiscuffing properties of the Army engine oils. A John Deere OEM axle equipped with JD-4230 final drives and solid differential is utilized as the basic test fixture. The axle is driven by a JD-4630 turbocharged-intercooled diesel engine through a JD-4630 power shift transmission. Final drive gears are loaded by means of a load brake on each axle. The brakes are oil cooled and the loads are controlled at set points by a load cell-servo controller loop.

The new sun pinions and planet pinion gears are installed, and the test axle housings are filled with the reference oil. The load is operated at 11,600 lb-ft of torque, 22 axle rpm, 195°F lubricant temperature, and maintained for 20 hours. At 20 hours, the axle speed is decreased to 11 rpm with 11,600 lb-ft torque at 195°F for 30 more hours. Upon the conclusion of the 50 hours on the reference oil, the axle housings are removed and the sun pinions measured for wear. The axle housings are cleaned and flushed with test oil and the left and right sun pinions interchanged (a

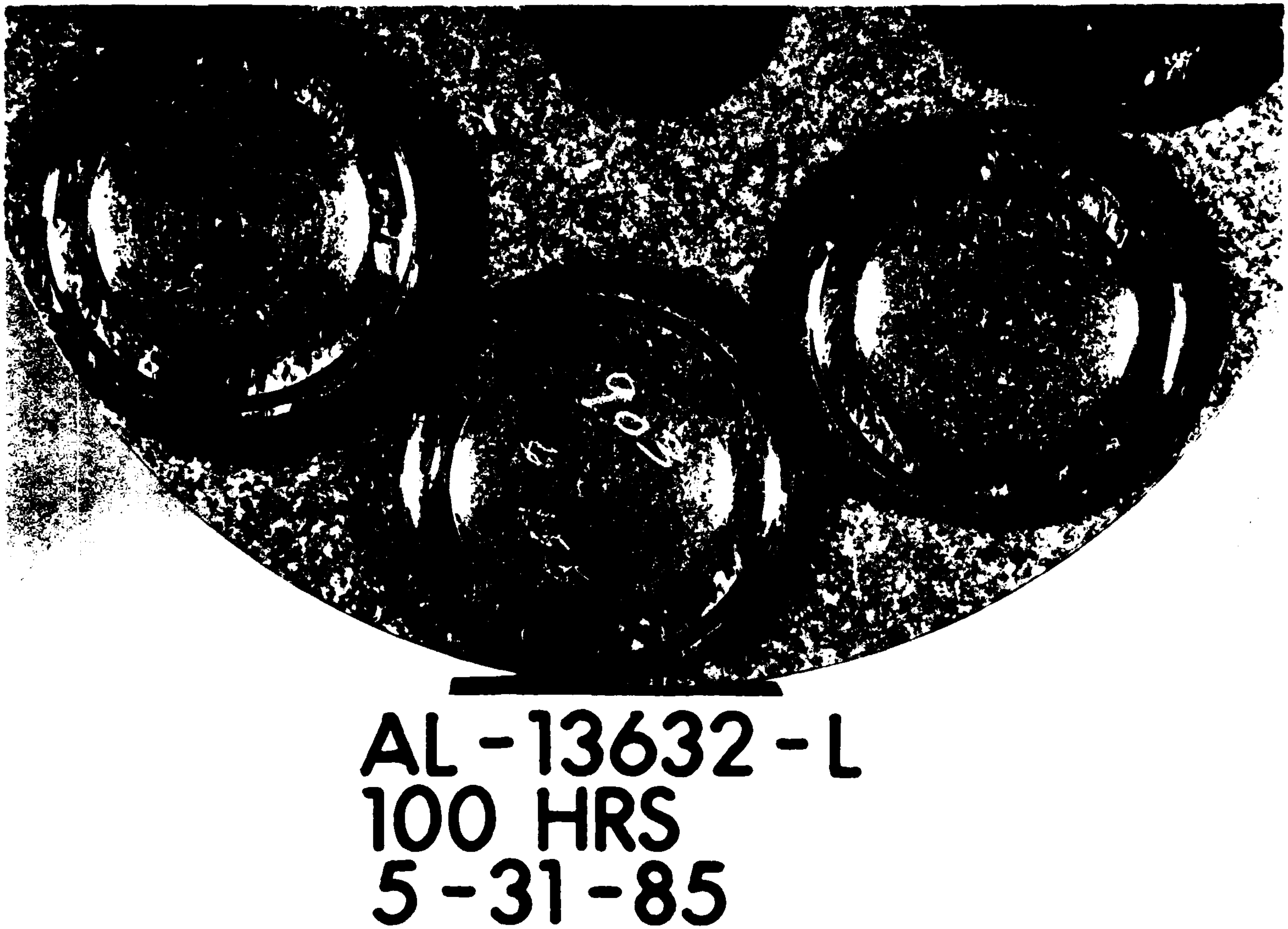

FIGURE 1. PISTON SHOE USING MIL-L-46167

FIGURE 2. BARREL SUPPORT BEARING USING MIL-L-46167

new surface). The axle is reassembled, filled with test oil, and the above conditions are repeated for 50 hours.

The data from these tests are shown in Table A-6. The antiwear and antiscuffing characteristics were compared to the good reference oil. The average values of each oil were obtained from the wear of 10 teeth (5 per gear). Since there are 15 teeth on each sun pinion gear, the measurements represent one-third of the total teeth. The general surface condition and wear with all five Army engine oils were superior to the reference oil, showing that these Army engine oils have good final drive antiwear properties.

C. ASTM and CEC Sintered Bronze Wet-Brake Fluid Friction Test

This test determines the effect of the oil properties on the wet-brake torque variation (chatter) and relative capacity performance. A John Deere 4000 series tractor is equipped with an instrumented axle and sun pinion shaft on the same side as the sintered bronze brake component under test. The opposite axle is restrained from rotation. The tractor is operated at various combinations of axle speeds, oil temperatures, and brake pressure. The brake is applied, and the resulting brake torque variation and capacity are recorded at various test operating conditions. These data are compared to the reference oil and must be comparable or better to pass.

These test results can be seen in Table A-7. The reference oil tests resulted in a brake chatter mean value of 64.5 lb-in. x 10^3 (7.3 kNm) with a standard deviation of 16.7 lb-in. x 10^3 (1.9 kNm). Based on the acceptance criterion, the maximum chatter value for an acceptable pass oil would be 81.2 lb-in. x 10^3 (9.2 kNm). Using this criteria, all the test oils failed. A relative ranking based on the chatter values are:

Lube No.	Grade	Results, lb-in. x 10^3	(kNm)	Ranking
2	30	97.7	(11.0)	Best
4	15W-40	127.6	(14.4)	↑
1	10W	127.7	(14.4)	
5	0W-20	139.7	(15.7)	
3	15W-40	157.2	(17.7)	Worse

The results for the observed mean for the relative capacity of the reference tests was 821 lb-in. x 10^3 (92.8 kNm) with a standard deviation of 57 lb-in. x 10^3 (6.4 kNm). Using one standard deviation as the acceptance criterion, Oil No. 3, a grade 15W-40, failed. The relative ranking is as follows:

Lube No.	Grade	Results, lb-in. x 10^3	(kNm)	Ranking
5	0W-20	824	(93.1)	Best
2	30	797	(90.1)	↑
1	10W	792	(89.5)	
4	15W-40	777	(87.8)	
3	15W-40	752	(84.9)	Worse

D. Copper Corrosion (ASTM D 130 Mod.)

This test detects the corrosiveness of petroleum products to copper. A polished copper strip is immersed in 30 mL of lubricant heated to 150° for 3 hours. The copper strip is removed, washed, and compared to the ASTM Copper Strip Standard. The test criterion of satisfactory performance is 1b maximum. The MIL-L-46167, grade 0W-20 and one of the MIL-L-2104D, grade 15W-40 lubricants passed the test with a 1a color rating. Three MIL-L-2104D lubricants--a grade 10W, grade 30, and grade 15W-40--failed the test with an ASTM color rating of 4b. This appears to indicate that the Army engine lubricants may need additional treatment to help prevent copper corrosion in hydraulic and power transmission fluid systems. It should be remembered that this test indicates a visual color change which occurs due to the reaction of active sulfur compounds with copper metal. Also, no actual weight loss measurements are made, only a visual color change effect is observed. When these three failed copper strips were observed under a microscope, they did not appear to have a large amount of corrosion, but rather a dark gray to black plating. The copper strips were then analyzed with the electron scanning microscope, which interfaces with an XRF analyzer. The plating on the copper strip, when analyzed with these instruments, was determined to be primarily zinc and sulfur and probably came from the lubricant additive package. Therefore, the correlation of these test results with field performance of lubricants is somewhat questionable as previous research on copper corrosion of gear oils has shown no trend or correlation.(11)

VI. CONCLUSIONS

The results from this work have shown that all five Army engine lubricants passed the Transmission Final Drive Gear Wear tests. Four lubricants passed the Denison HF-0 Piston and Vane Pump test, while the MIL-L-46167, grade 0W-20 passed the vane pump part but failed the piston pump part. All five lubricants had more wet-brake chatter than the reference oil in the ASTM and CEC Sintered Bronze Wet-Brake Fluid Friction test. The MIL-L-2104D, grade 10W, grade 30, and one grade 15W-40 had poorer results in the Copper Corrosion Test than the manufacturer's requirements or the proposed ASTM Multipurpose Power Transmission requirement.

Data compiled from this and previous work have shown that the limiting factors of the Army engine oils used as hydraulic and multipurpose power transmission fluids appear to be (1) wet-brake chatter noise, (2) hydraulic pump wear problems with some piston pumps using MIL-L-46167 Arctic engine oils at temperatures hotter than expected Arctic conditions and (3) possibly copper corrosion/reactivity.

The prime area of concern is the wet-brake chatter noise.

VII. RECOMMENDATIONS

The only equipment at this time in the Army CCE and SHME inventory that uses wet-brakes is the John Deere Model 410 front loader/backhoe tractor. The fluids recommended for this vehicle are the fluids meeting the John Deere JDM-J20A specification. The JDM-J20A specification procedure 5.1 and 5.2 (Wet-Brake Chatter and Capacity Test) uses asbestos and woven bronze wire where the Army procured JD-410 vehicle uses graphic material. There is no available correlation between the asbestos and graphitic material, except that experience has shown the graphitic friction material usually does not chatter as much. There also is no standard field test used by John Deere for the JD-410. John Deere personnel have recommended that for field testing the JD-410 tractor, the actual in-vehicle test that was conducted and developed at Ft. Belvoir in 1977 by Belvoir F&L Research Facility in conjunction with John Deere personnel, should be used as guidelines to evaluate the various lubricants as a field test.(5) Therefore, it is recommended

that the Belvoir F&L Research Facility In-Vehicle Wet-Brake Chatter Noise and Hydraulic Performance test should be used to evaluate various lubricants.

The old MIL-L-46167 failed the Denison HF-0 Piston and Vane Pump test and the ASTM and CEC Sintered Bronze Wet-Brake Fluid Friction test and has exhibited other borderline pump wear test problems. The new revision "A" was to be evaluated but qualified oils were not yet available. Currently only one lubricant is qualified under the "A" revision, and no other lubricants have been submitted for qualification. Therefore, the new MIL-L-46167A lubricant should be evaluated in the following four tests:

- Denison HF-0 Piston and Vane Pump Test
- Transmission Final Drive Gear Wear Test
- ASTM and CEC Sintered Bronze Wet-Brake Fluid Friction Test
- Copper Corrosion

Based on current results and the above-recommended evaluations, the suitability of various military engine specification lubricants for use in field hydraulic and power transmissions could be determined, and an assessment of the trade-offs of using these lubricants in CCE and SMHE equipment could be made at a relatively low-risk level.

VIII. REFERENCES

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APPENDIX
TEST RESULTS

TABLE A-1. P46 PISTON PUMP TEST SUMMARY--LUBE NO. 1, GRADE 10W

PART NAME	INITIAL INSPECTION	60 HOUR INSPECTION	100 HOUR INSPECTION
PORT PLATE	OK	Slight cavitation cloud at bleed slot. Very fine circular scratches. Circular polishing.	More circular polishing.
FACE PLATE	OK	Circular polishing on inside of ports. Greyish deposits between ports	More circular polishing.
CREEP PLATE	Polished cam surface with 600 grit sandpaper.	Slight greyish discoloration.	More greyish discoloration.
PISTON SHOES	OK	Slight blackish deposits. Very slight darkening.	No apparent change from 60 hours.

T5D VANE PUMP TEST SUMMARY

CAM RING	Burred ports.	Slight marking at step over points. Machine marks still visible. Slight markings at discharge ramp.	Slight ripple at ports.
VANE CONTOURS	Avg. Leading 0.004 in. Avg. Trailing 0.004 in.	Avg. Leading 0.007 in. Avg. Trailing 0.007 in.	Avg. Leading 0.010 in. Avg. Trailing 0.008 in.
SIDE PLATE	OK	Very fine circular polishing.	Slightly more polishing.
ROTOR	OK	No apparent change from 0 hour.	No apparent change from 60 hour.

TABLE A-2. P46 PISTON PUMP TEST SUMMARY—LUBE NO. 2, GRADE 30

PART NAME	INITIAL INSPECTION	60 HOUR INSPECTION	100 HOUR INSPECTION
PORT PLATE	OK	Circular polishing. Fine circular scratches.	Dark circular ring on outside edge. Circular polishing. Slight cavitation cloud at bleed slot.
FACE PLATE	OK	Dark deposits between ports. Black circular ring on inside of ports. Polishing on outside edge.	Darkening. More polishing.
CREEP PLATE	Polished cam side with 600 grit sandpaper.	Greyish discoloration. Slight darkening. Random bronze streaks.	More darkening. Fine random scratches. Slightly more greyish discoloration.
PISTON SHOES	OK	Random scratches. Slight darkening.	Lands darkened.

T5D VANE PUMP TEST SUMMARY

CAM RING	Burred ports.	Slight markings at stepover points. Machine marks still visible. Slight markings at discharge ramp.	More markings at stepover points. Machine marks slightly visible.
VANE CONTOURS	Avg. Leading 0.004 in. Avg. Trailing 0.004 in.	Avg. Leading 0.008 in. Avg. Trailing 0.008 in.	Avg. Leading 0.011 in. Avg. Trailing 0.011 in.
SIDE PLATE	OK	Very fine polishing.	Slightly more polishing.
ROTOR	OK	No apparent change.	No apparent change.

TABLE A-3. P46 PISTON PUMP TEST SUMMARY--LUBE NO. 3, GRADE 15W-40

PART NAME	INITIAL INSPECTION	60 HOUR INSPECTION	100 HOUR INSPECTION
PORT PLATE	OK	Circular polishing. Fine circular scratches. Slight cavitation cloud at bleed slot.	More polishing. More circular scratches.
FACE PLATE	OK	Blackened.	More blackening.
CREEP PLATE	Polished cam side with 600 grit sandpaper.	Greyish discoloration. Random streaks.	No apparent change from 60 hours.
PISTON SHOES	OK	Lands slightly darkened. Shoe six has four voids on lands.	Lands darkened. Voids slightly bigger. Random scratches.

T5D VANE PUMP TEST SUMMARY

CAM RING	Burred ports.	Markings at step over points. Machine marks still visible. Slight markings at discharge ramp.	More markings at step over points. Machine marks not visible. Markings at discharge ramp.
VANE CONTOURS	Avg. Leading 0.004 in. Avg. Trailing 0.004 in.	Avg. Leading 0.008 in. Avg. Trailing 0.008 in.	Avg. Leading 0.009 in. Avg. Trailing 0.009 in.
SIDE PLATE	OK	Slight circular polishing.	Slightly more circular polishing.
ROTOR	OK	No apparent change.	Very slight circular polishing.

TABLE A-4. P46 PISTON PUMP TEST SUMMARY—LUBE NO. 4, GRADE 15W-40

PART NAME	INITIAL INSPECTION	60 HOUR INSPECTION	100 HOUR INSPECTION
PORT PLATE	OK	Circular polishing. Slight cavitation cloud at bleed slot.	Slightly more circular polishing.
FACE PLATE	OK	Circular polishing. Black circular ring on inside of ports.	More polishing.
CREEP PLATE	Polished cam side with 600 grit sandpaper.	Blueish discoloration. Very fine circular scratches. Slight circular polishing.	Circular polishing.
PISTON SHOES	OK	Fine random scratches. Lands darkening.	Lands slightly darkened.

T5D VANE PUMP TEST SUMMARY

CAM RING	Burred ports.	Markings at step over points. Slight markings at discharge ramp.	Slightly more markings at step over points. More markings at discharge ramp.
VANE CONTOURS	Avg. Leading 0.005 in. Avg. Trailing 0.004 in.	Avg. Leading 0.009 in. Avg. Trailing 0.009 in.	Avg. Leading 0.010 in. Avg. Trailing 0.010 in.
SIDE PLATE	OK	Very fine circular polishing.	Circular polishing
ROTOR	OK	Very fine circular polishing.	No apparent change.

TABLE A-5. P46 PISTON PUMP TEST SUMMARY--LUBE NO. 5, GRADE 0W-20

PART NAME	INITIAL INSPECTION	60 HOUR INSPECTION	100 HOUR INSPECTION
PORT PLATE	OK	Fine circular scratches. Slight polishing. Cavitation cloud at bleed slot.	More polishing.
FACE PLATE	OK	Very slight darkening. Circular polishing.	Deep circular scratches on outside edge.
CREEP PLATE	Polished cam side with 600 grit sandpaper.	Greyish discoloration. Random streaks.	No significant change from 60 hour inspection.
PISTON SHOES	OK	Slight darkening. Random scratches.	Scoring. Remaining surface area very dark.

T5D VANE PUMP TEST SUMMARY

CAM RING	Burred ports.	Machine marks visible. Marking at stepover points. Very slight markings at discharge ramp.	Markings at discharge ramp.
VANE CONTOURS	Avg. Leading 0.005 in. Avg. Trailing 0.005 in.	Avg. Leading 0.010 in. Avg. Trailing 0.009 in.	Avg. Leading 0.012 in. Avg. Trailing 0.010 in.
SIDE PLATE	OK	Very slight polishing.	More polishing.
ROTOR	OK	No change from 0 hour inspection	No apparent change.

TABLE A-6. COMPARISON OF WEAR ON SUN PINION GEAR ARMY LUBRICANT VERSUS J20A REFERENCE OIL

	Lubricant No. 1 Wear, Inches		J20A Reference Oil Wear, Inches	
	Right Gear	Left Gear	Right Gear	Left Gear
1)	0.0010	0.0011	0.0027	0.0025
2)	0.0011	0.0012	0.0026	0.0026
3)	0.0011	0.0011	0.0027	0.0026
4)	0.0010	0.0011	0.0029	0.0028
5)	0.0010	0.0011	0.0028	0.0026
Average	0.0010	0.0011	0.0027	0.0026
Average Right and Left	0.0011		0.0026	

	Lubricant No. 2 Wear, Inches		J20A Reference Oil Wear, Inches	
	Right Gear	Left Gear	Right Gear	Left Gear
1)	0.0009	0.0008	0.0025	0.0026
2)	0.0011	0.0010	0.0027	0.0025
3)	0.0010	0.0010	0.0027	0.0025
4)	0.0008	0.0010	0.0026	0.0024
5)	0.0010	0.0009	0.0026	0.0025
Average	0.0010	0.0009	0.0026	0.0025
Average Right and Left	0.0010		0.0025	

	Lubricant No. 3 Wear, Inches		J20A Reference Oil Wear, Inches	
	Right Gear	Left Gear	Right Gear	Left Gear
1)	0.0010	0.0010	0.0026	0.0027
2)	0.0009	0.0008	0.0028	0.0024
3)	0.0010	0.0009	0.0027	0.0025
4)	0.0008	0.0008	0.0026	0.0027
5)	0.0008	0.0008	0.0026	0.0024
Average	0.0009	0.0009	0.0027	0.0025
Average Right and Left	0.0009		0.0026	

TABLE A-6. COMPARISON OF WEAR ON SUN PINION GEAR ARMY LUBRICANT VERSUS J20A REFERENCE OIL (CONT'D)

	Lubricant No. 4 Wear, Inches		J20A Reference Oil Wear, Inches	
	Right Gear	Left Gear	Right Gear	Left Gear
1)	0.0011	0.0011	0.0026	0.0024
2)	0.0012	0.0010	0.0025	0.0025
3)	0.0010	0.0009	0.0026	0.0025
4)	0.0011	0.0010	0.0026	0.0026
5)	0.0010	0.0010	0.0027	0.0025
Average	0.0011	0.0010	0.0026	0.0025
Average Right and Left	0.0011		0.0026	

	Lubricant No. 5 Wear, Inches		J20A Reference Oil Wear, Inches	
	Right Gear	Left Gear	Right Gear	Left Gear
1)	0.0015	0.0013	0.0027	0.0026
2)	0.0015	0.0013	0.0026	0.0025
3)	0.0014	0.0014	0.0027	0.0027
4)	0.0014	0.0013	0.0025	0.0026
5)	0.0015	0.0015	0.0025	0.0025
Average	0.0015	0.0014	0.0026	0.0026
Average Right and Left	0.0014		0.0026	

TABLE A-7. ASTM/CEC WET-BRAKE FRICTION TEST

Oil No.	Temp, °F	Relative Capacity, lb-in X 10^3 (kNm)		Chatter, lb-in X 10^3 (kNm)	
1	90	172		33.3	
	120	197		34.5	
	140	212		31.8	
	160	211		29.0	
		792	(89.5)	127.7	(14.4 kNm)
2	90	157		14.0	
	120	196		22.3	
	140	212.5		30.5	
	160	226		30.8	
		797.5	(90.1)	97.7	(11.0)
3	90	144		27.1	
	120	188		40.6	
	140	202		45.5	
	160	216		44.0	
		751.5	(84.9)	157.2	(17.7)
4	90	132		20.5	
	120	176		27.7	
	140	198		40.7	
	160	210		38.6	
		777	(87.8)	127.6	(14.4)
5	90	177		30.3	
	120	200		35.3	
	140	221		36.6	
	160	226		37.3	
		824	(93.1)	139.7	(15.7)

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